Public Workshop on Dynamic Rollover and Handling Test Techniques

Welcome to the Vehicle Research and Test Center!

Workshop Agenda

• 10:00 am	Welcome and Introductions
• 10:15 am	Presentation on Instrumentation
• 10:45 am	Presentation on Outriggers
• 11:00 am	Presentation on Test Maneuvers
• 11:30 am	Presentation on Test Procedures
• 12:00 pm	Lunch
• 1:00 pm	Inspection of Vehicles (in lab)
• 2:00 pm	End of Meeting

Public Workshop on Dynamic Rollover and Handling Test Techniques

Instrumentation

Garrick J. Forkenbrock

NHTSA / VRTC

Sensor Overview

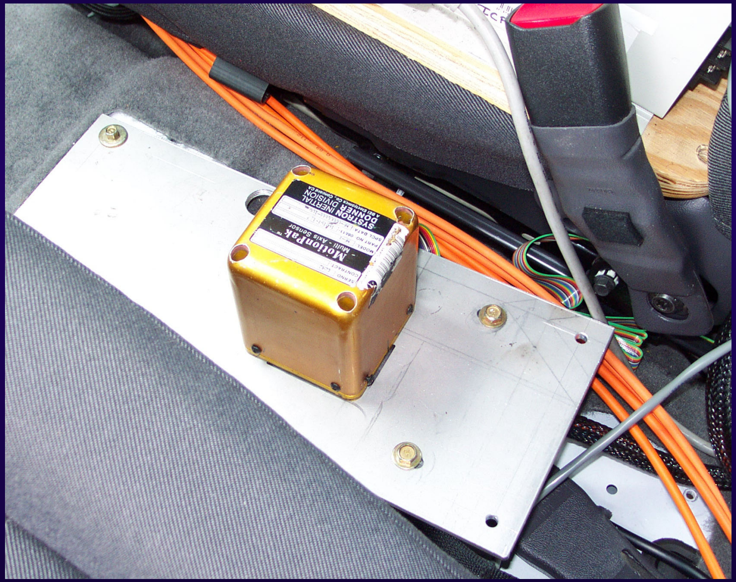
- Steering Machine
- Accelerometers (A_x, A_y, A_z)
- Rates (V_x, V_y, V_z)
- Ultrasonic Distance Measuring System
- Laser Distance Measuring System
- Vehicle Speed
- Brake Pedal Force
- GPS

Steering Machine

- VRTC uses an ATI steering machine
- Other controllers may be used
- Must be able to apply steering rates of up to 1000 deg/sec over the vehicle's mechanical range with good linearity
- Handwheel angle outputs recommended

Accelerations and Rates

- VRTC uses solid state, "inertial grade" quartz accelerometers and micromachined quartz angular rate sensors
  - Drift-free
  - Very low nonlinearity
- Drift-free roll rate signals are particular important
- A_y data is corrected for roll effects during post processing



Placement of Accelerometers

- Accelerometers are positioned near vehicle C.G.
- Mounting location does not change regardless of load configuration
- Data is later corrected for offset with actual C.G. position data

Ultrasonic Distance Measuring System

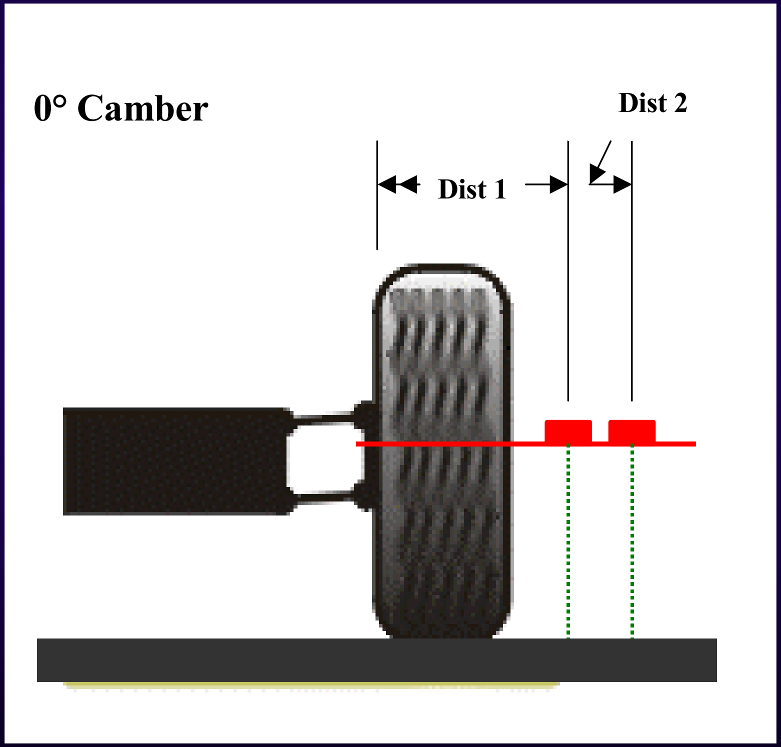
- Sensors are installed near the longitudinal center of gravity on both sides of the vehicle
- Sensor data is resolved during post processing to produce chassis roll angle
- Cost is reasonable

Laser Distance Measuring System

- Two laser sensors are mounted parallel to the wheel and aligned vertically with the axle
- Sensor data is resolved in the field and during post processing to remove camber effects and output wheel lift
- Cost is reasonable
- Front stator assemblies made on a per vehicle basis
- Wheel adapters are modular

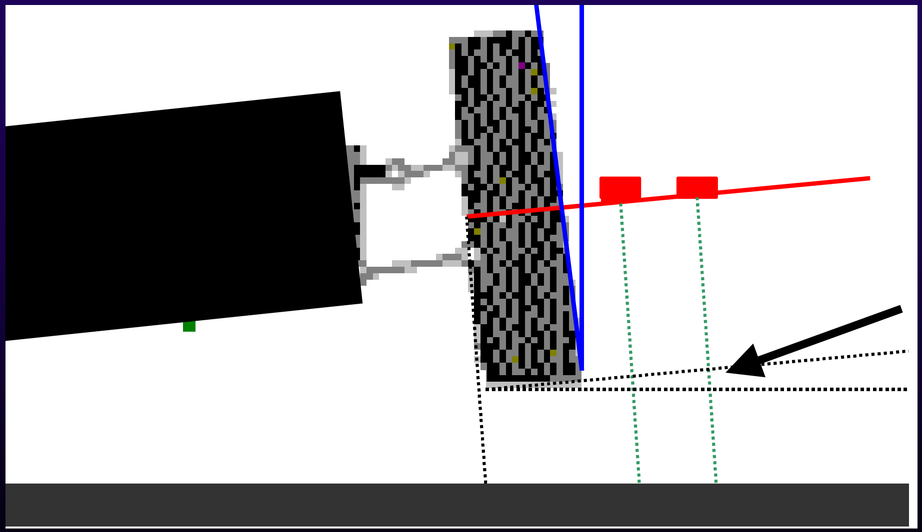
Laser Sensor Diagram

- **Known quantities**
  - Dist 1 = distance between the first laser sensor and the inside corner of the tread
  - Dist 2 = distance between laser sensors
- **Zeroing**
  - Zero defined as the tire just touching ground at 0° camber angle



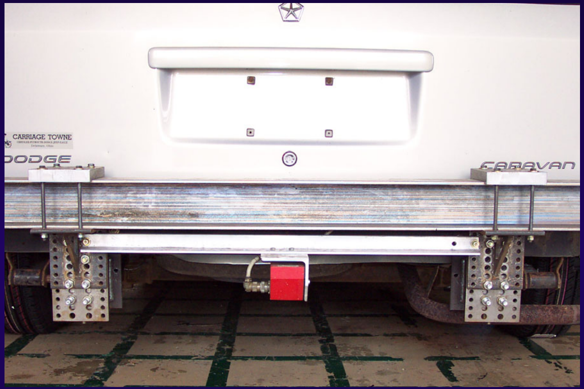
Wheel Lift Calculation

1. Use laser wheel height sensor data to calculate camber angle.
2. Using known camber angle, corrects wheel lift height.



Vehicle Speed

- Doppler-based
- Light-weight
- Easy to install
- Sensor output is fed to DAS and a dash-mounted display
- May need to be repositioned when load configurations are changed



Brake Pedal Force

- Sensor attached to face of the brake pedal
- Data is used to confirm the driver did not apply the brakes during a maneuver

GPS

- GPS data only required for Dropped Throttle in a Turn tests (path deviation)
- Requires 20 minute pre and post test static calibrations
- Use of differential post processing allows highly accurate results

Additional Mnemonics

- **Roll Flag**
  - Acknowledgement roll rate has entered the window comparator
  - Used to confirm correct steering reversal timing during Road Edge Recovery tests
- **Handwheel Start**
  - Based on the steering machine's internal clock
  - Clock paused between completion of initial steer and initiation of steering reversal
  - Simplifies dwell time calculation

Additional Mnemonics

- **Trigger**
  - Reference for the synchronization of data from the data acquisition systems
- **Throttle**
  - Throttle position data output from the vehicle's TPS is collected
  - Used to monitor driver inputs during two Handling Maneuvers

Data Collection

- Most channels sampled at 200 Hz
- Raw GPS data collected at 10 Hz with a separate DAS
  - Supersampling allows GPS data to be synchronized with other data
- Analog filtering
  - Most channels used a two-pole low-pass Butterworth filter
  - Nominal cutoff frequencies selected to prevent aliasing
  - Calculated breakpoint frequencies were 18 and 19 Hz for the first and second poles, respectively, for most channels
  - The handwheel angle channel required higher nominal breakpoint frequencies; 1800 and 1900 Hz were used for the first and second poles, respectively

Post Processing

- Most channels filtered with a 6 Hz, 12-pole, 2-pass, phaseless digital Butterworth filter
- A Kalman filter was applied to GPS data during post processing
- All accelerations were corrected for C.G. displacement
- A_y data corrected for roll effects during post processing
- A_Y also filtered with a [separate] 400 ms running average technique
  - Used when determining $A_{Y,max}$
- Laser height measurements filtered with a 200 ms running average technique

Questions?

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NHTSA Outriggers

Garrick J. Forkenbrock

NHTSA / VRTC

Presentation Overview

- Outrigger development
  - Objectives
  - Comparison of three designs
- "Short" outrigger discussion
- Outrigger mounting
- Dissemination of outrigger specifications

Outrigger Development

Objectives

- Reduce the influence of outrigger installation on static vehicle parameters and dynamic responses
- Preserve driver safety

Comparison of Three Designs

- Previous VRTC Design
  - 6061 T6 Aluminum
- Current VTRC Design
  - 6Al-4V Titanium
- Carr Engineering
  - Carbon fiber

NHTSA 6061 T6 Aluminum Outriggers

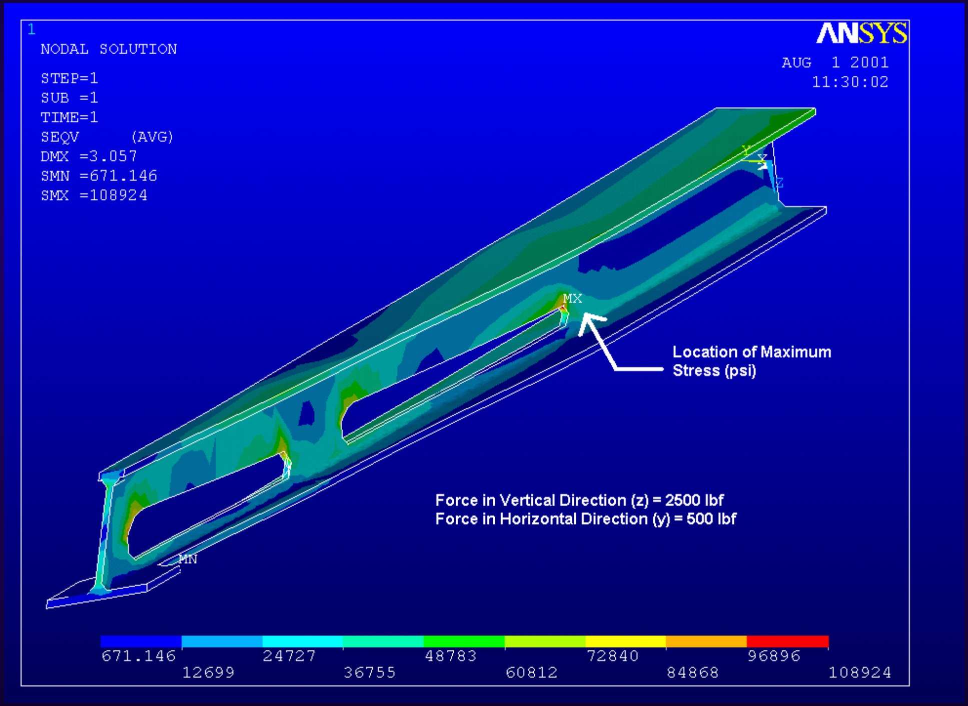
- Height is adjustable in two ways
- Cost is low
- Can be produced in-house
- Durable
- Somewhat heavy (78 lbs)

Carbon Fiber

- Manufactured by Carr Engineering
- Strong
- Expensive
- Light weight (58 lbs)

NHTSA Titanium Outriggers

- Designed at VRTC using finite element analysis
- CNC machined
- Strong
- Nearly 1/3 cost of carbon fiber
- 6Al-4V a common Ti alloy
- Low-mu hemispherical skid pads replace heavier caster assemblies
- Light weight (58 - 63 lbs)



Effect of Outriggers on Static Parameters

1 = least effect 3 = most effect

Category	Carbon Fiber	Titanium	Aluminum
Outrigger Weight	1	2	3
Roll Inertia	2	1	3
Yaw and Pitch Inertia	1	1	3
CG Height	1	1	3

Titanium Outrigger Chosen As NHTSA's Preferred Outrigger

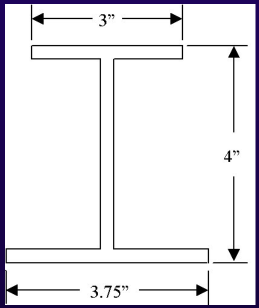
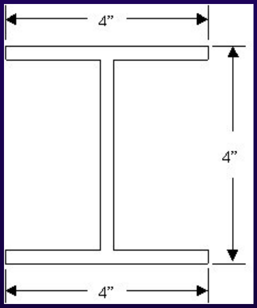
- **Pros**
  - Safe for driver
  - Strong
  - Lowest roll inertia influence of the three designs compared
  - Cost much less than carbon fiber
  - Use light-weight skid pads
  - Not much heavier than carbon fiber design
- **Cons**
  - Slightly heavier than carbon fiber
  - Cost greater than aluminum
  - Can not be machined in-house

NHTSA's "Short" Outriggers

NHTSA “Short” Outriggers

- **Titanium construction**
- **For vehicles < 3500 lbs in the Baseline Condition**
- **Design similar to “Standard” Titanium Outriggers**
  - **Some mounts can be interchanged**
  - **Identical skid pads**

NHTSA Outrigger Comparison

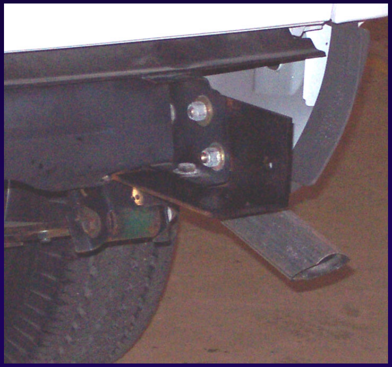
Description	Short	Standard
Length	135 inches	147 inches
Flange/Web Thickness	0.25 inches	0.25 inches
Weight	57.5 lbs	63.3 lbs
Cross-section		
Moment of Inertia About Roll and Yaw Axes (Through Outrigger C.G.)	19.6 ft-lb-s^2	24.2 ft-lb-s^2

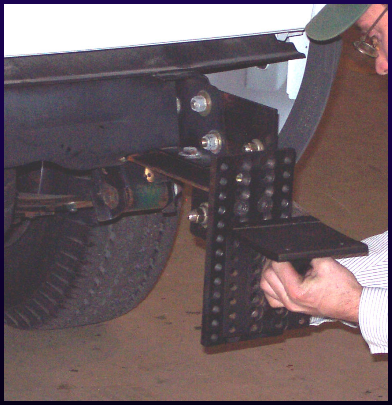
Outrigger Mounting

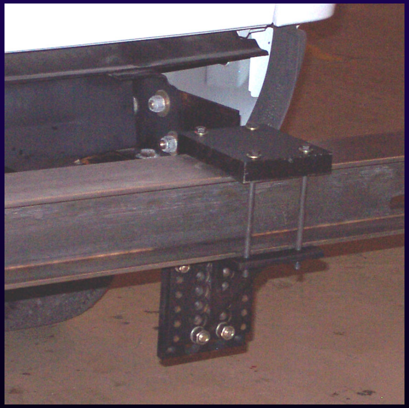
Outrigger Height

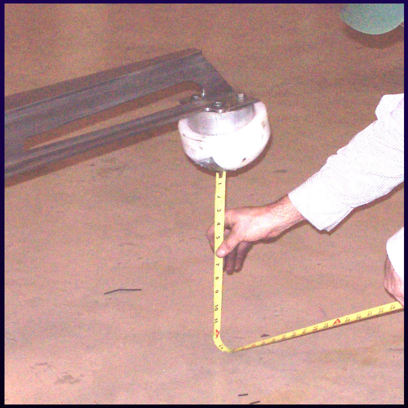
- "Standard" Outrigger Initial Settings
  - Bottom of skid pad to ground ≈14 inches
- "Short" Outriggers Initial Settings
  - Bottom of skid pad to ground ≈12 inches
- Height increased if front or rear outrigger-to-ground contact is made
  - 1 inch increments used at affected corner of vehicle
- Different test loads usually requires different mount-to-outrigger orientation to achieve initial settings

Typical Installation









Dissemination of Outrigger Specifications

Available soon…

- Detailed Drawings
  - "Standard" and "Short" Titanium Outriggers
  - Mounts and skid pads
- Outrigger CNC code
  - Files to machine exact replicas of NHTSA's "Standard" and "Short" titanium outriggers

Questions?

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Maneuver Descriptions

Garrick J. Forkenbrock

NHTSA / VRTC

Background

- **TREAD Act / Congressional Requirements:**
  - Develop dynamic rollover propensity tests to facilitate a consumer information program
- **National Academy of Sciences Report (Jan. ’02)**
  - “NHTSA should vigorously pursue the development of dynamic testing to supplement the information provided by SSF.”

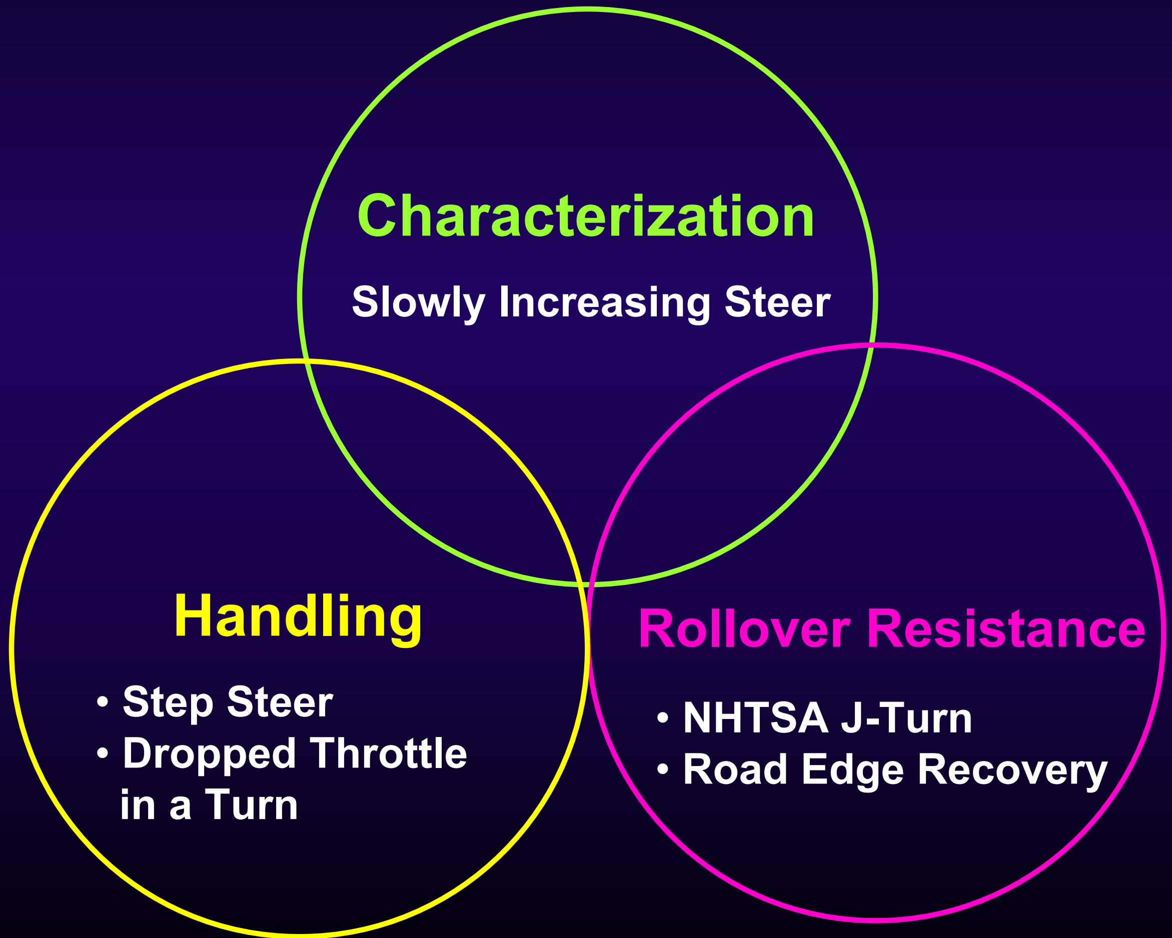
Overview

- NHTSA's current Rollover Resistance maneuvers selected based on Phase IV evaluation of maneuvers
- Handling maneuvers selected based on our previous experience maneuver and our need to quantify handling

Topics Discussed

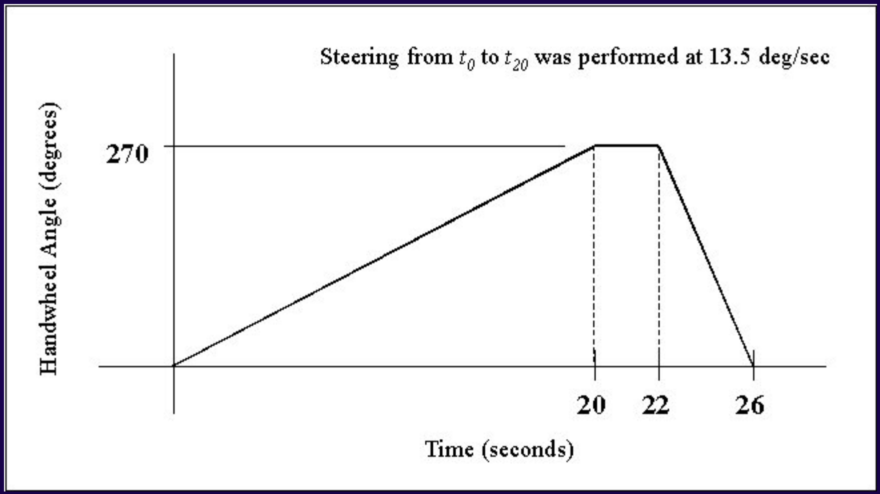
- Handwheel steering inputs used to define NHTSA's Rollover Resistance and Handling maneuvers
- Maneuver speeds
- Measured parameters of each maneuver

Maneuver Relationship



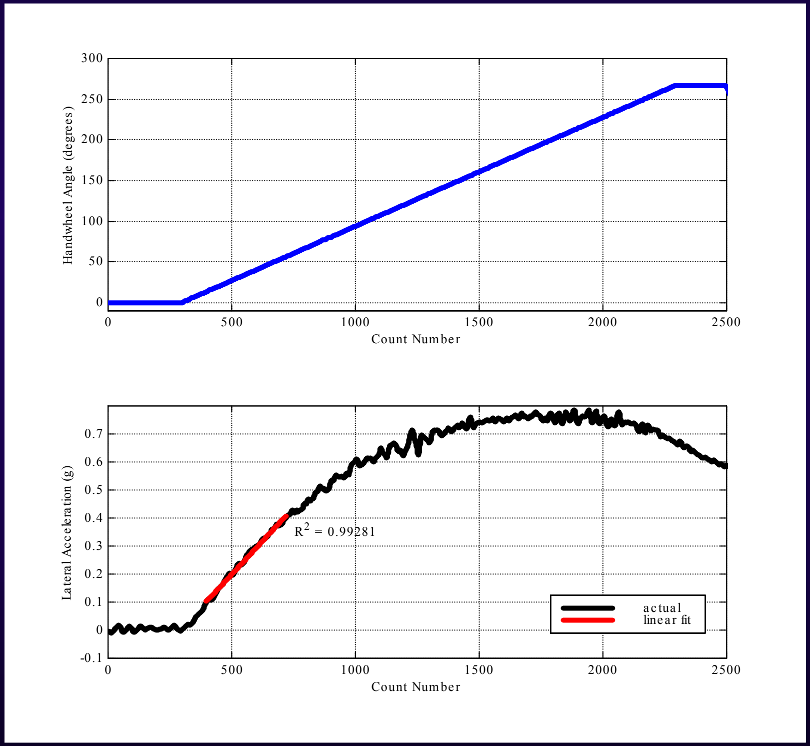
Slowly Increasing Steer (SAE J266)

- **50 mph test speed**
  - Driver modulates throttle to maintain constant speed
- **Measured parameters**
  - Maximum lateral acceleration
  - Limit behavior
    - Understeer
    - Oversteer
  - Overall average handwheel position at certain lateral accelerations



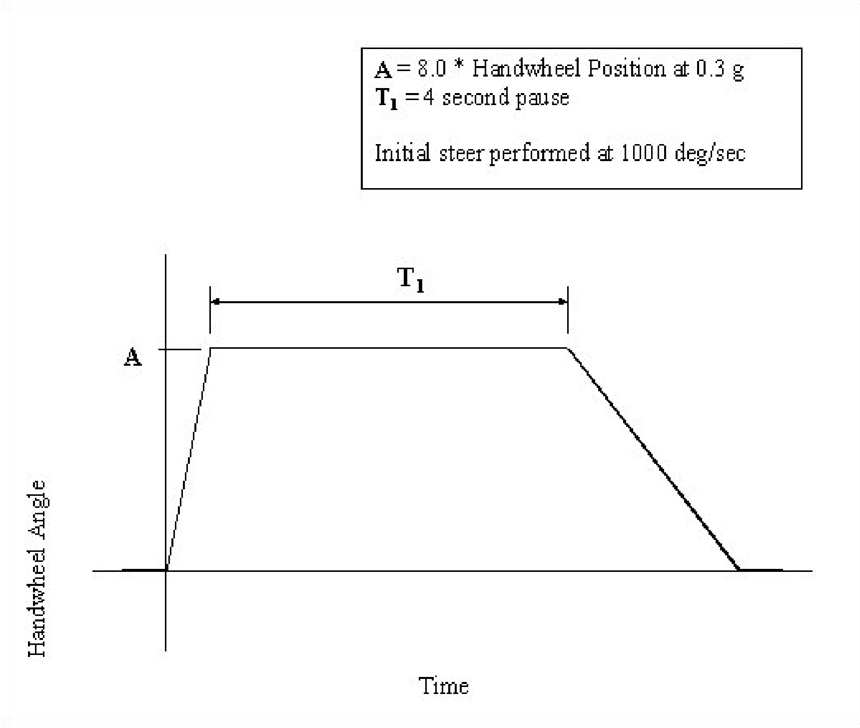
NHTSA J-Turn and Road Edge Recovery

- Steering magnitude based on vehicle response
  1. Determine the handwheel angle at 0.3 g from Slowly Increasing Steer results
  2. Multiply by a scalar (derived from Phase II data)
- Steering rate based on successful Phase II testing
  – J-Turn = 1000 deg/sec
  – Road Edge Recovery = 720 deg/sec



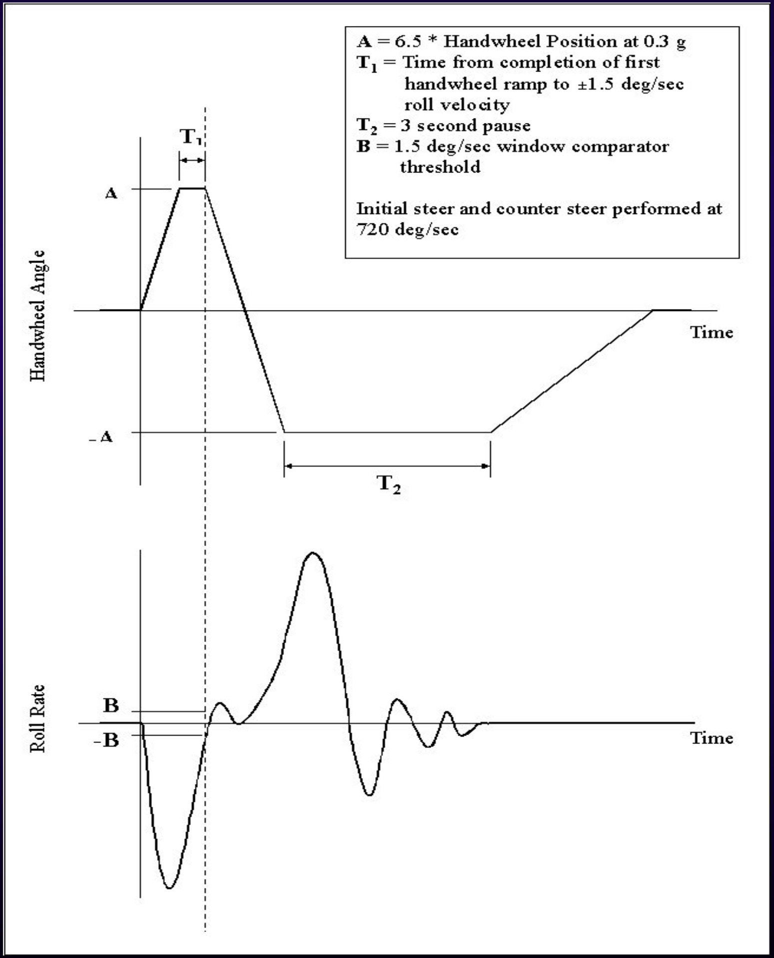
NHTSA J-Turn

- 35 to 60 mph maneuver entrance speeds
- Performed with "dropped-throttle" only
- Measured parameter
  - Minimum maneuver entrance speed capable of producing two-wheel lift



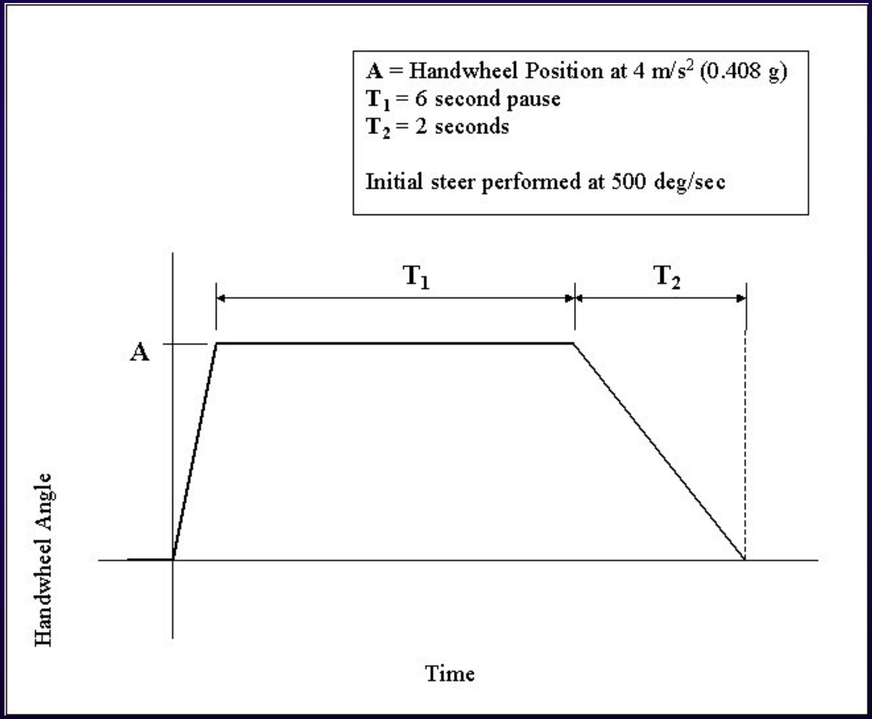
NHTSA Road Edge Recovery

- 35 to 50 mph maneuver entrance speeds
- Performed with "dropped-throttle" only
- Measured parameters
  - Minimum maneuver entrance speed capable of producing two-wheel lift
  - Roll rate feedback functionality
  - Handwheel dwell time



Step Steer
(ISO 7401)

- 50 mph maneuver entrance speed
- Driver maintains constant throttle position



Step Steer (ISO 7401)

Measured parameters

– **Yaw rate response time**

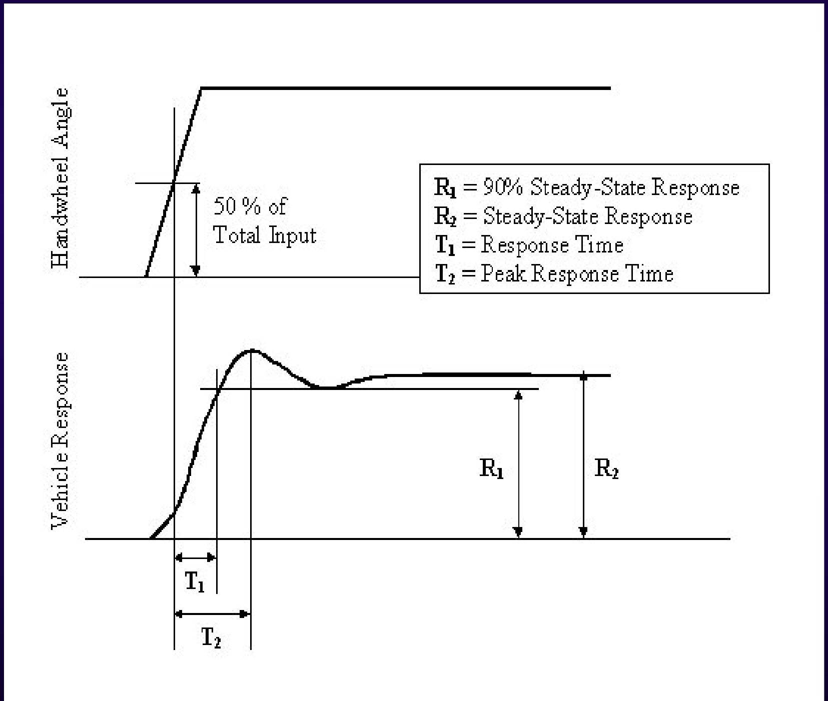
$$T_{\dot{\psi}} = t_{90\% \cdot \dot{\psi}_{ss}} - t_{ref}$$

– **Yaw rate peak response time**

$$T_{\dot{\psi},max} = t_{\dot{\psi},max[1]} - t_{ref}$$

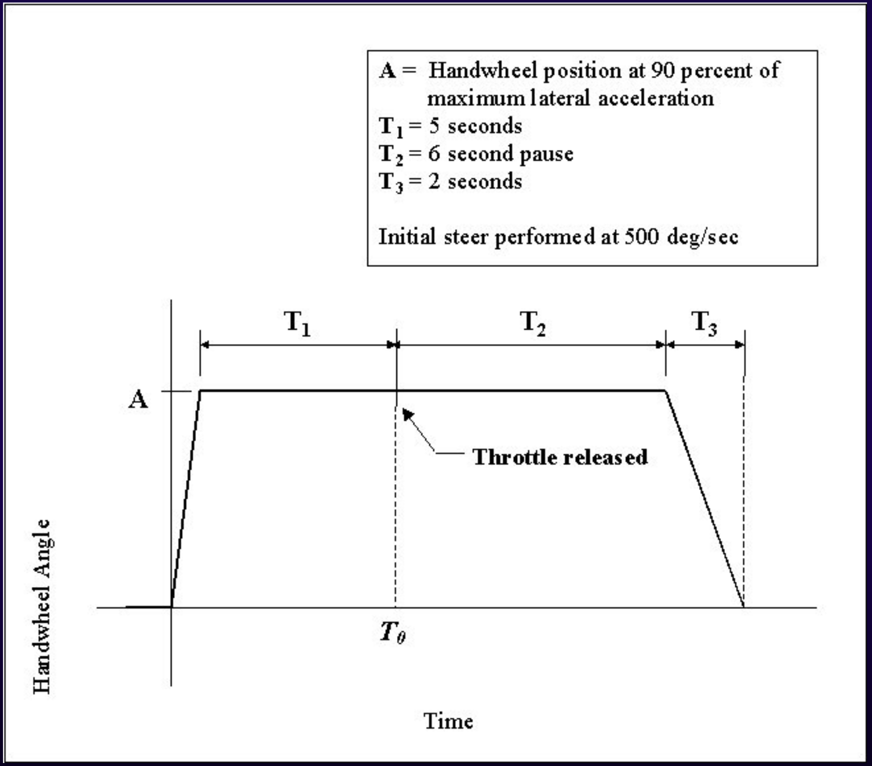
– **Yaw rate overshoot ratio**

$$Percent\ Overshoot = 100 \times \left(\frac{\dot{\psi}_{max} - \dot{\psi}_{ss}}{\dot{\psi}_{ss}} \right)$$



Dropped Throttle in a Turn
(ISO 9816)

- 50 mph maneuver entrance speed
- Driver releases throttle after steady-state was achieved



Dropped Throttle in a Turn
(ISO 9816)

Measured parameters

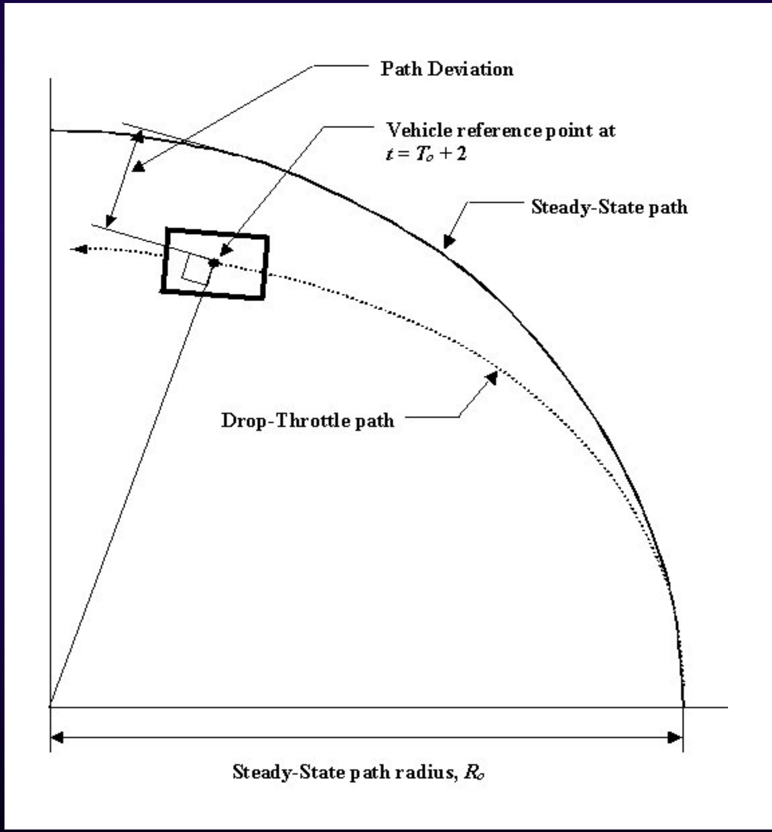
– **Ratio of a maximum and steady state yaw rate**

$$\frac{\dot{\psi}_{max}}{\dot{\psi}_{0}}$$

where $\dot{\psi}_{max}$ = maximum yaw rate from $t = T_0$ to $t = T_0 + 3$

– **Path deviation**

Deviation from steady state path at $t = T_0 + 2$



Questions?

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Test Procedures

Garrick J. Forkenbrock

NHTSA / VRTC

Test Surface

Test Surface Requirements

- All tests must be performed on a dry, high-mu surface
  - VRTC's tests are performed on the TRC Vehicle Dynamics Area (VDA)
  - VDA skid numbers for calendar year 2002
    - Measured using standard ASTM procedures
    - Peak mu: 0.92 to 0.99
    - Slide mu: 0.82 to 0.88
- Surface irregularities can confound test outcome, and should thus be avoided

Vehicle Orientation on Test Surface

- The TRC VDA has a 1% north-to-south slope
- NHTSA's tests are initiated during "uphill" approaches

  Requires the Drop Throttle in a Turn to begin "downhill" so steady state may be achieved prior to the throttle release

Vehicle Configurations

All vehicles are…

- Instrumented
- Fully fueled
- Equipped with front and rear mounted outriggers
- Evaluated with multiple load configurations
  - Nominal Load
  - Maximum Occupancy
  - Rear Load
  - C.G. measured for each configuration
- Tested with enabled stability control, if applicable

Vehicle Gear Selection

- With few exceptions, all tests are performed with automatic transmissions in “Drive”, manual transmissions in highest gear capable of sustaining the desired test speed
  – For some vehicles, the Slowly Increasing Steer tests require a lower gear to be selected (manual transmission)
  – Drop Throttle in a Turn tests require the transmission be placed in a gear that allows engine to be closest to peak power at 50 mph
- The clutch is not disengaged during any maneuver

Nominal Load Configuration

- Used for Rollover Resistance and Handling Maneuvers
- Instrumentation ≈ 150 lbs
- "Small" Outriggers
  - 58 lbs per beam
  - ≈26 lbs of hardware per beam
- "Standard" Outriggers
  - 63 lbs per beam
  - ≈35 lbs of hardware per beam

Maximum Occupancy Configuration

- Used for Rollover Resistance maneuvers only
- Phase VI intent ⇨ one water dummy placed in each designated rear seating position
- A full water dummy weighs 178lbs
- In some cases, vehicle GAWRs and/or GVWR were exceeded when a full water dummy was placed in each designated rear seating position
  - If this occurred, partially filled water dummies were used to reduce weight
  - If water was removed from a water dummy, foam was added to prevent slosh
- NHTSA does <u>not</u> intend to test vehicles above their respective GAWRs and/or GVWR

Rear Load

- Used for Handling maneuvers only
- Rear GAWR and vehicle GVWR achieved simultaneously
- Ballast ⇨ bags of lead shot
  - Positioned as flat as possible across the rear cargo area
  - Secured in a manner that prevents shifting, typically in a plywood box

Tires

Tires

- **OEM specification (as installed when delivered)**
  - Make
  - Model
  - DOT Code
  - Inflation pressure
- **Steps to reduce debeading**
  - Inner tubes
  - No tire lubricant used when tires are mounted

Definition of “Test Series”

- A test series is defined as one maneuver performed with both possible steering combinations in one load configuration
- Example: A J-Turn test series uses left and right steering inputs with either Nominal or Maximum Occupancy loading

Tire Changes

- **Most maneuvers used a new tire set per test series**
  - **Slowly Increasing Steer**
  - **NHTSA J-Turn**
  - **NHTSA Road Edge Recovery**
- **Some maneuvers shared a single tire set per test series, per load configuration**
  - **Step Steer (not severe, only performed at 0.408 g)**
  - **Dropped Throttle in a Turn**

Tire "Scrub-In"

- NHTSA no longer uses 100 miles of mild test track driving for test preparation
- Current procedure:
  - Drive vehicle around a 100 ft diameter circle at a lateral acceleration of 0.5 - 0.6 g
    - 6 laps total
    - 3 per direction of steer
  - 1 Hz sinusoidal steering for 10 cycles at 0.5 - 0.6 g (δ_{ss})
    - 4 passes
    - Final cycle of final pass performed at 2*(δ_{ss})
- Tests are performed immediately after scrub-in

Rollover Resistance Maneuvers

Definition of "Two-Wheel Lift"

- Simultaneous front and rear wheel lift greater than or equal to 2"
- Two-wheel lift less than 2" is not reported
- Two-wheel lift so great that outrigger contact is made is simply reported as "two-wheel lift" as long as it was least 2" before outrigger contact was made with the ground

Iteration of Maneuver Entrance Speed

- **Upwards**
  - Increases severity
  - 5 mph increments
  - Selected to minimize tire wear
- **Downwards**
  - Used to isolate minimum entrance speed capable of producing two-wheel lift, if it occurs
  - 1 mph increments until two-wheel lift is no longer produced

Example of Entrance Speed Iteration

- **Scenario:**
  - A vehicle is being evaluated with the J-Turn maneuver.
  - Maneuver entrance speeds of 35, 40, 45, and 50 mph do not produce two-wheel lift.
  - The next test, performed at 55 mph, results in two-wheel lift.
- **The entrance speed is now reduced in 1 mph increments until two-wheel lift no longer occurs.**
- **The minimum entrance speed capable of producing two-wheel lift is reported.**

Handling Maneuvers

Step Steer

- Very straight-forward procedure
- Constant throttle position can be monitored via TPS
- Low lateral severity ⇨ minimal tire wear

Dropped Throttle in a Turn

- Throttle released only after steady state has been achieved
- Least repeatable of NHTSA's Rollover Resistance / Handling maneuvers
  - Throttle release not presently automated
  - Throttle position at steady state is vehicle-dependent
  - Vehicle position on test surface at throttle release somewhat variable
  - Throttle modulation can have a strong influence on test outcome

Questions?